Transit Science with JWST:
Program Status and Capabilities

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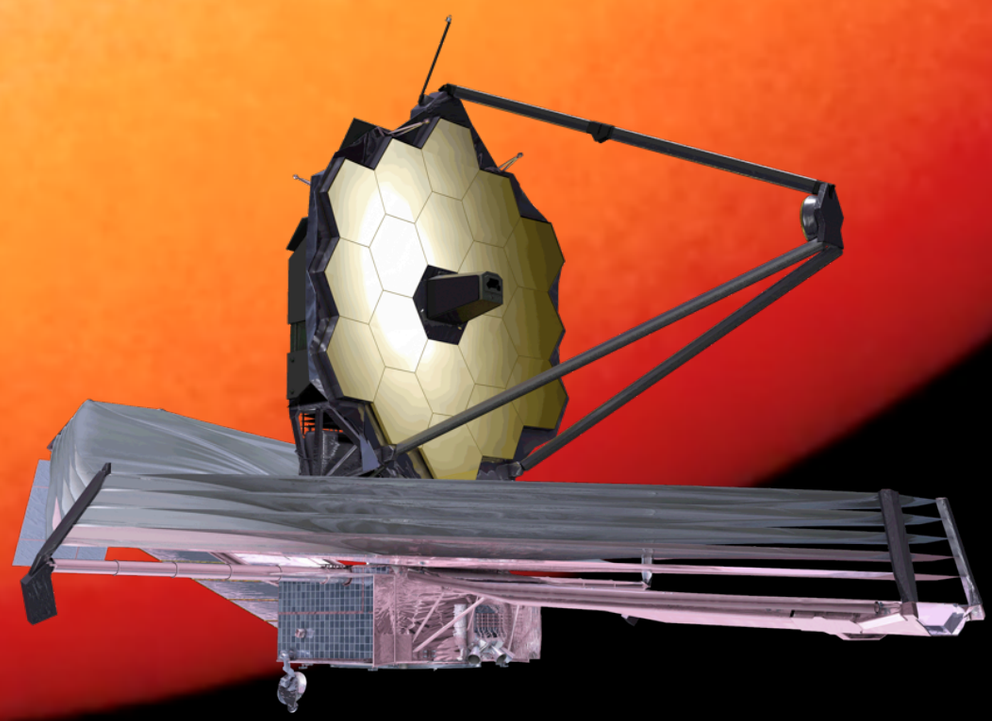
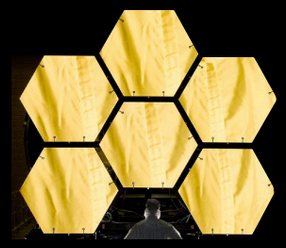
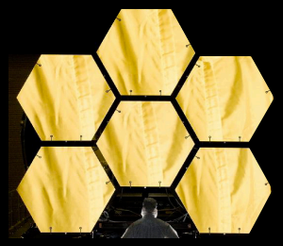


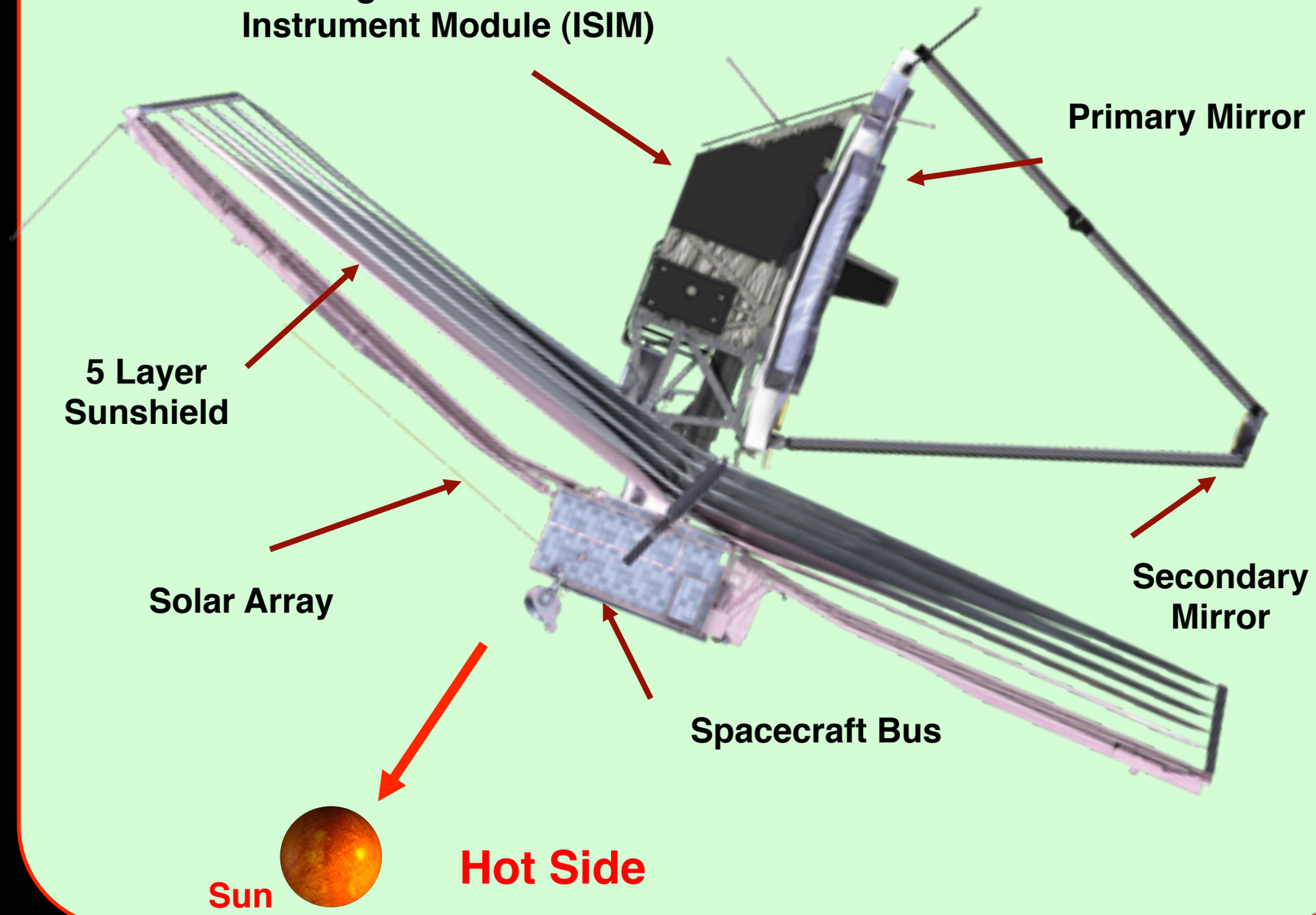
Objectives

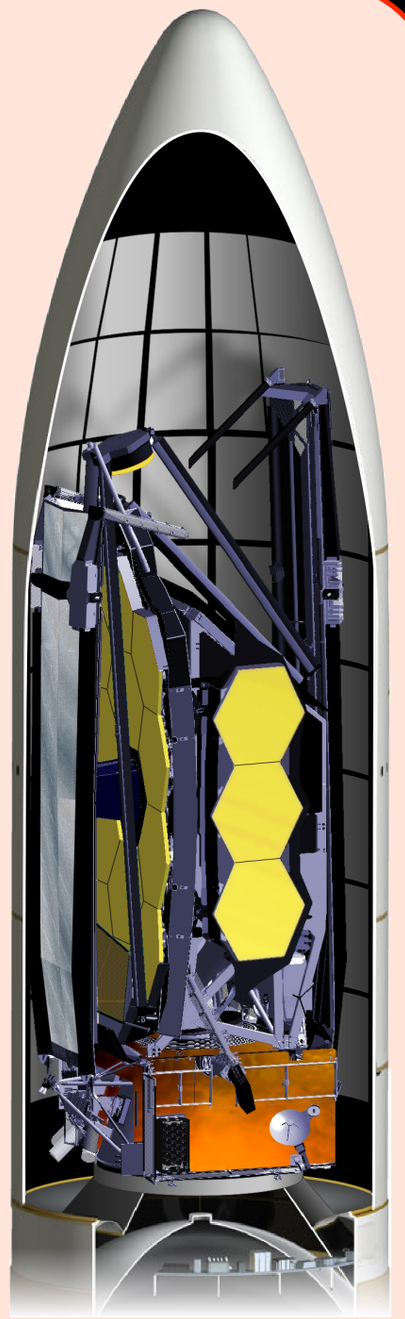


- **Status of JWST program**
  - ➡ JWST will be extensively used by exoplanet community: Inform community on progress
- **Two presentations at last EXOPAG**
  - ➡ **Today we address questions raised:**
    - ➡ What are the practical constraints and capabilities of the Observatory ?
    - ➡ What is being done to support Transit science
- **Future updates can address other issues**

How JWST Works

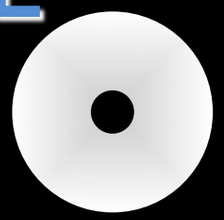




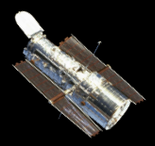


JWST and its Precursors

HUBBLE

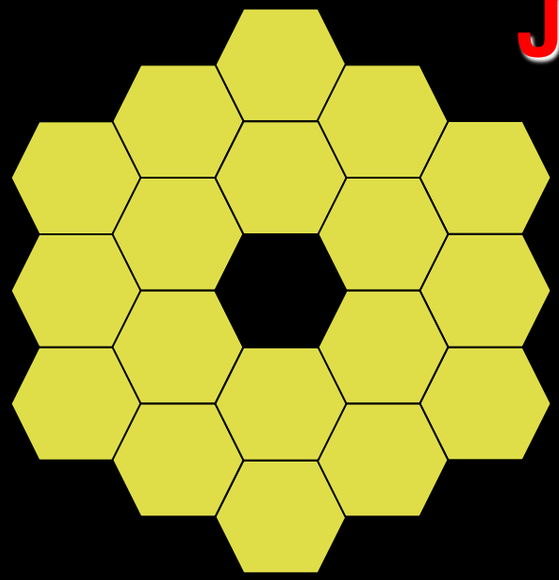


2.4-meter
T ~ 270 K

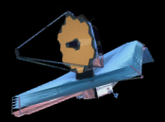


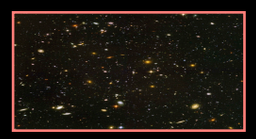
123” x 136”
$\lambda/D_{1.6\mu m}$~ 0.14”

JWST



6.5-meter
T ~ 40 K



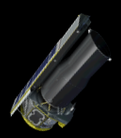


132” x 164”
$\lambda/D_{2\mu m}$~ 0.06”

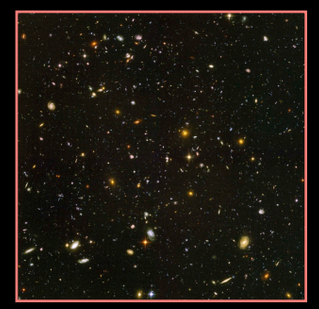
114” x 84”
$\lambda/D_{20\mu m}$~ 0.64”

SPITZER

0.8-meter
T ~ 5.5 K

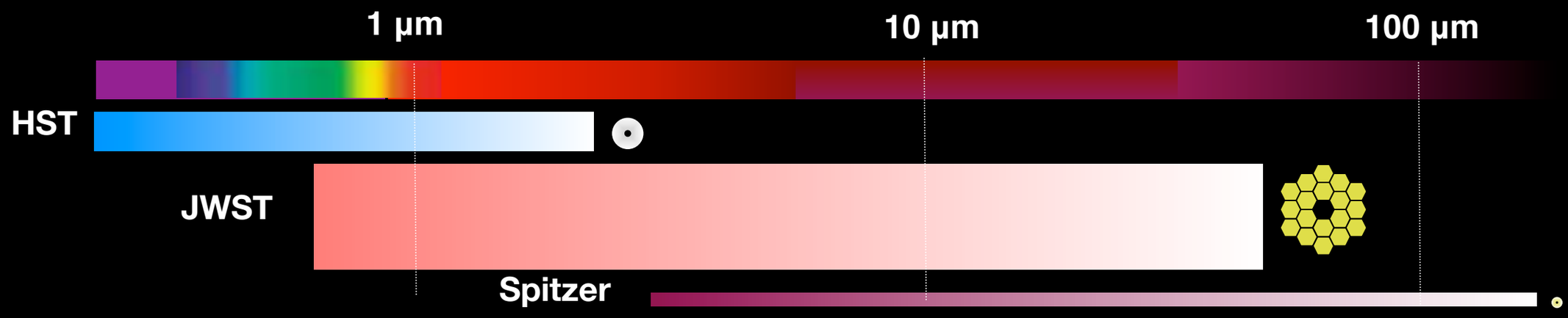


312” x 312”
$\lambda/D_{5.6\mu m}$~ 2.22”

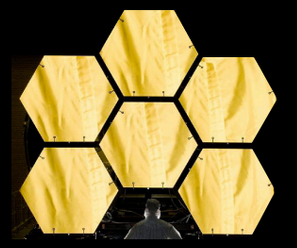


324” x 324”
$\lambda/D_{24\mu m}$~ 6.2”

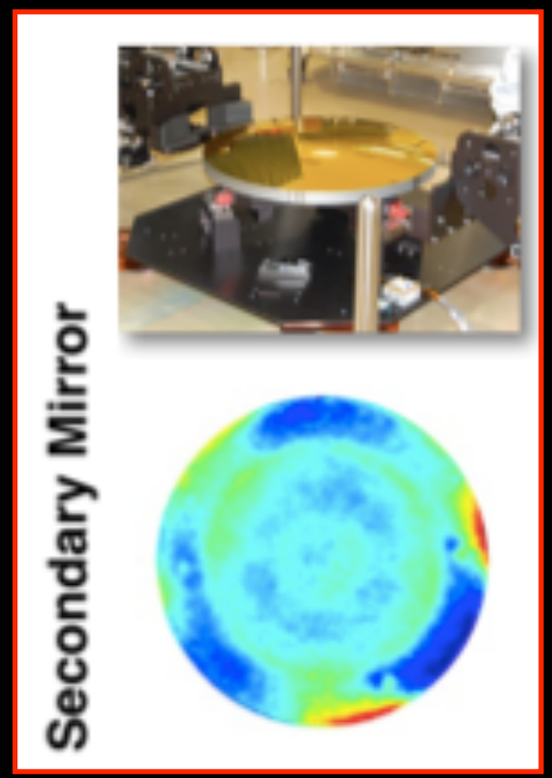
Wavelength Coverage

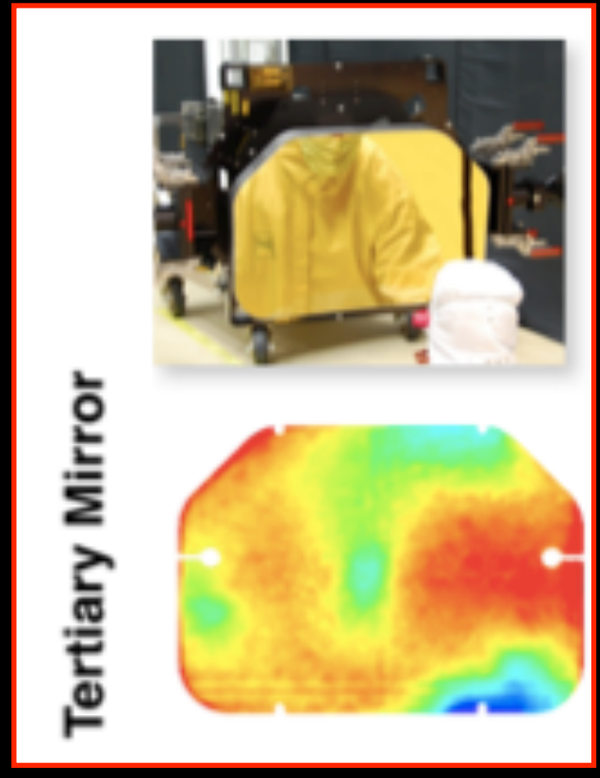


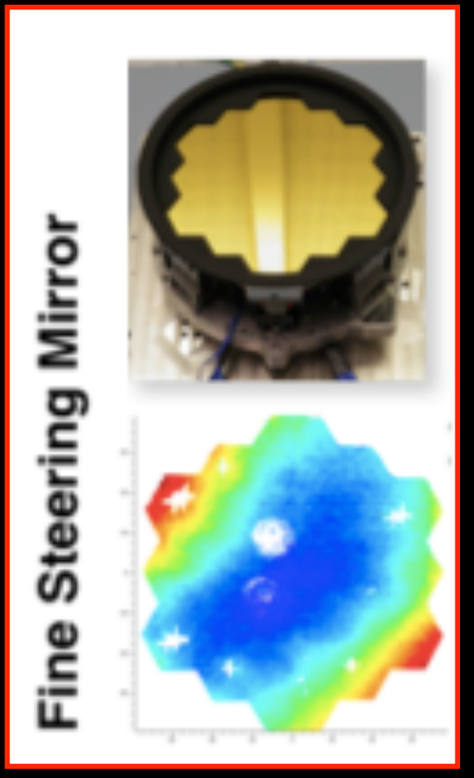
JWST Mirrors Completed in 2011



Mirror	Measured (RMS SFE)	Uncertainty (RMS SFE)	Total (RMS SFE)	Requirement (RMS SFE)
18 primary Segments (Composite Figure)	23.6	8.1	25.0	25.8
Secondary	14.7	13.2	19.8	23.5
Tertiary	18.1	9.5	20.5	23.2
FSM	13.9	4.9	14.7	18.7

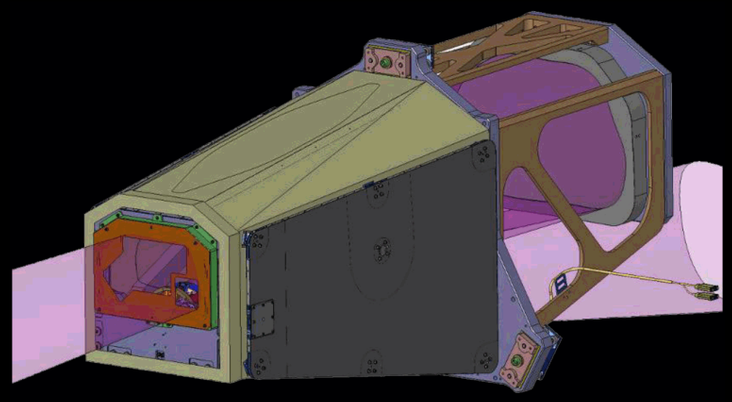


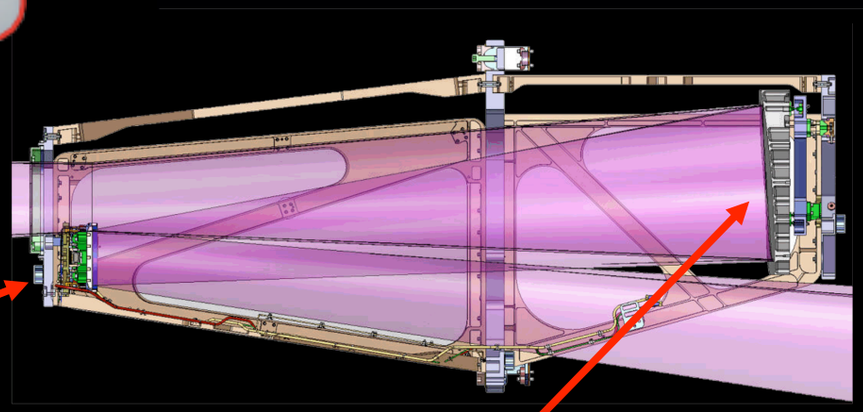


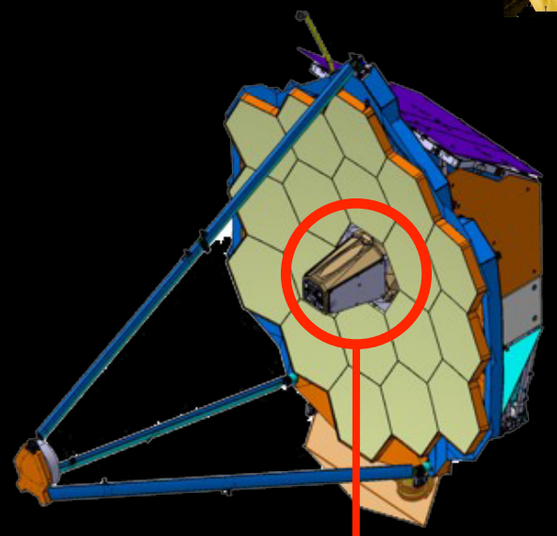


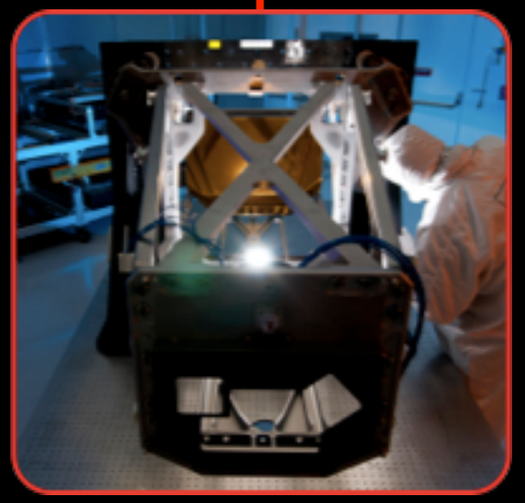
Aft-Optical System (AOS): Completed

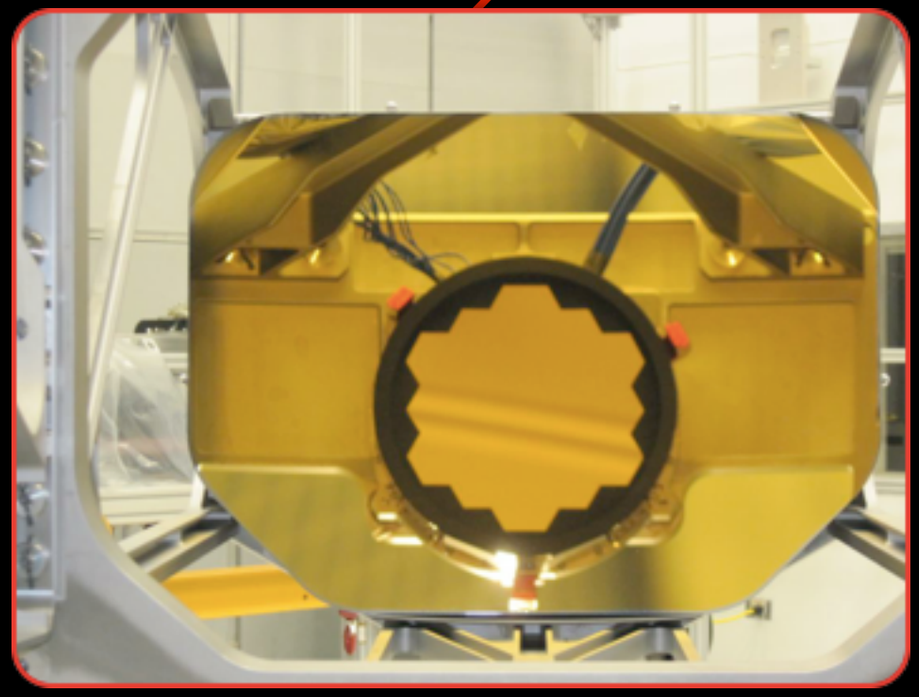
Aft optics and optical bench complete

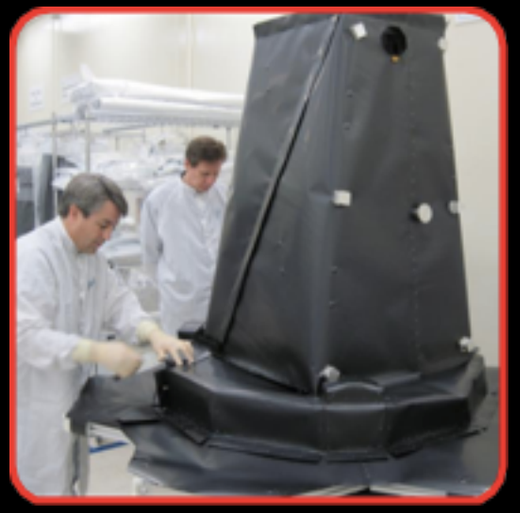




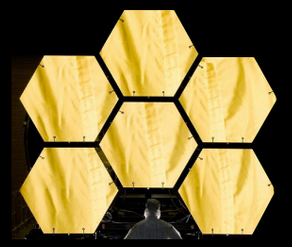






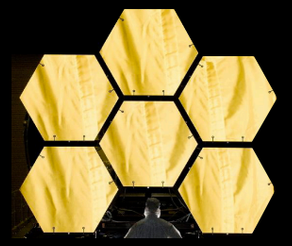


Primary Mirror Backplane Structures

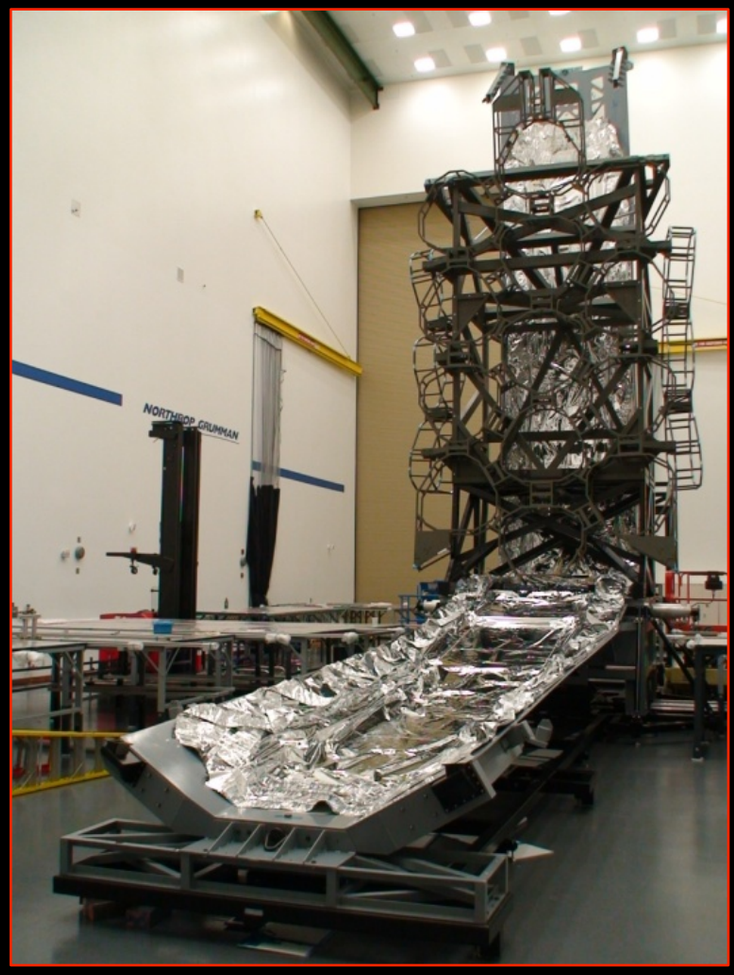


- Pathfinder backplane (central section) is complete
- Flight Backplane center section complete
  - ➡ Backplane Support Structure under construction
  - ➡ Wing sections under construction
- Next step: cryo-test of structures at MSFC

Sunshield

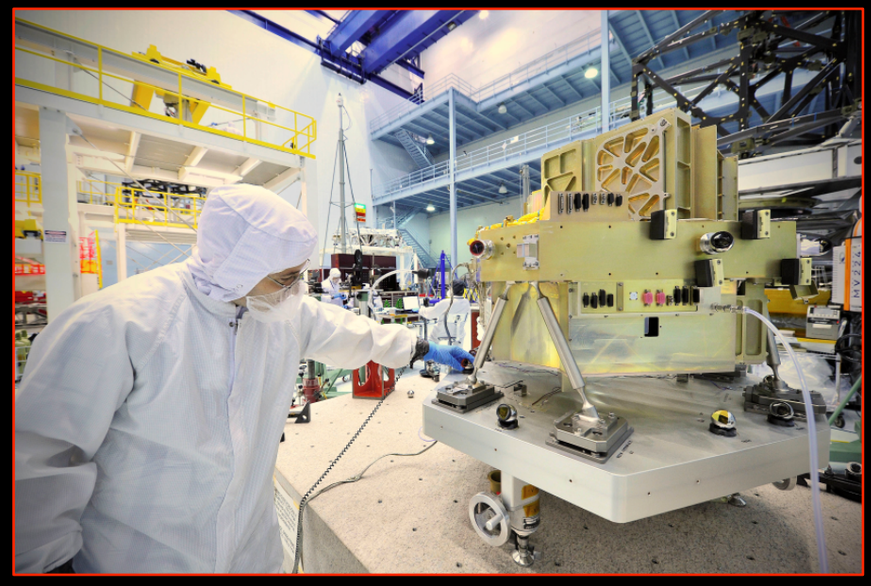


- Sunshield flight-like template layers completing construction
  - ➡ Designed to verify dimensions and 3-D shape under tension
  - ➡ Test deployment concepts on full-scale mockup

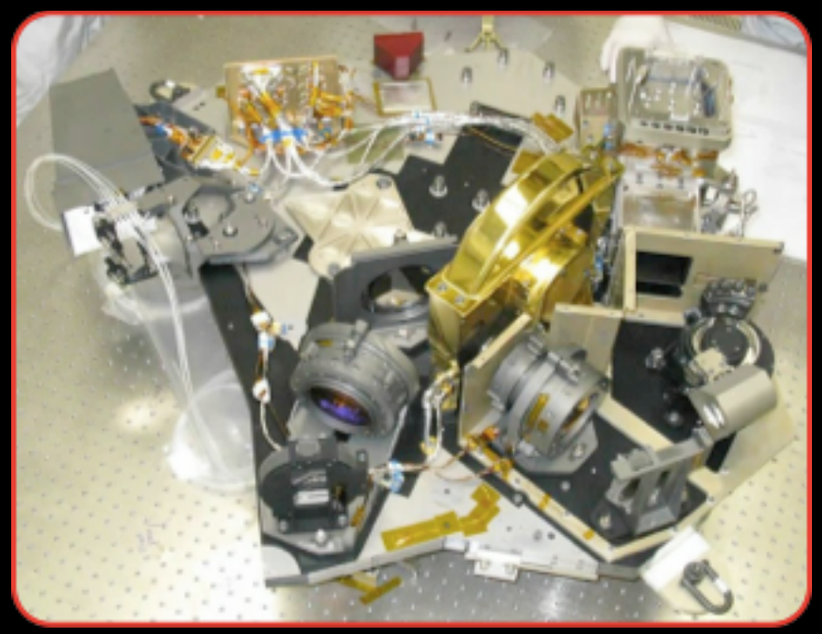


Science Instrument Status

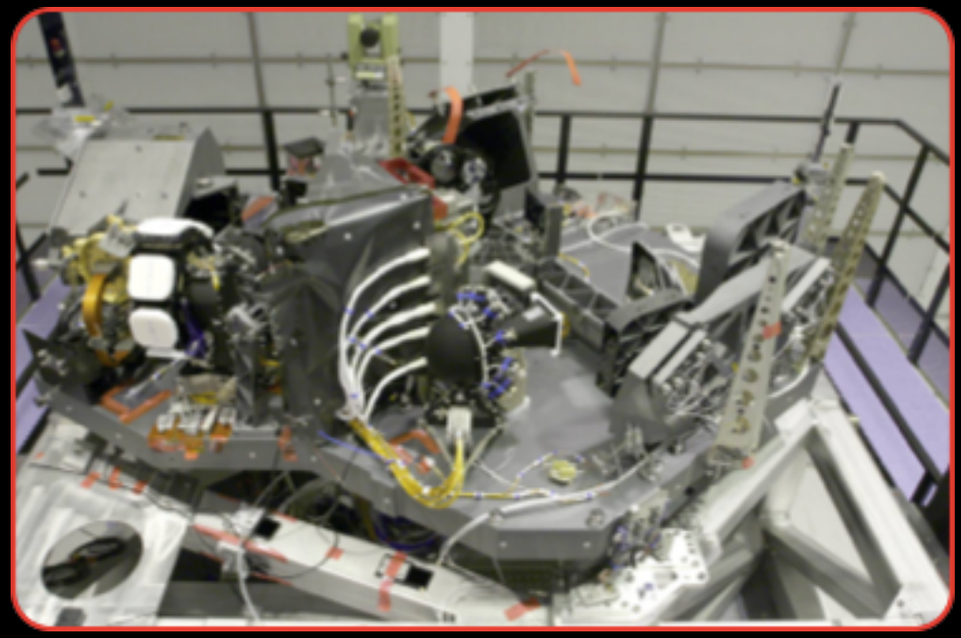
MIRI delivered to GSFC



NIRISS/FGS delivered to GSFC

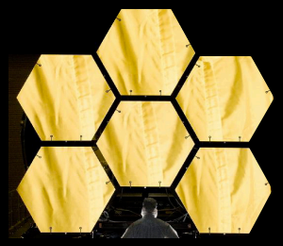


NIRSpec ready to start cryotesting
- delivery to GSFC in 2013

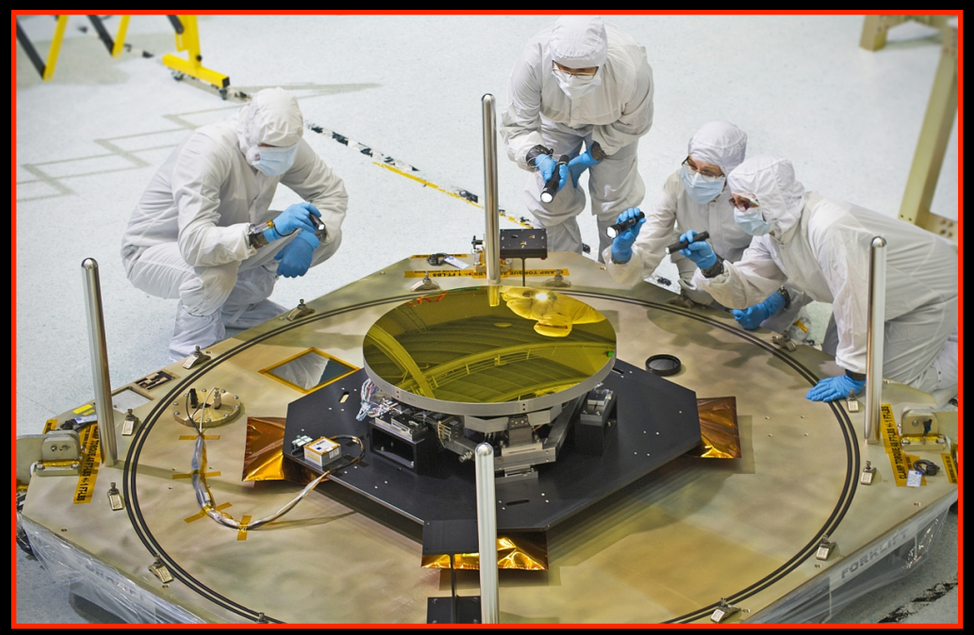


NIRCam completing cryotesting
- delivery to GSFC in 2013

JWST Mirrors Shipping to GSFC



Primary Mirror Segment



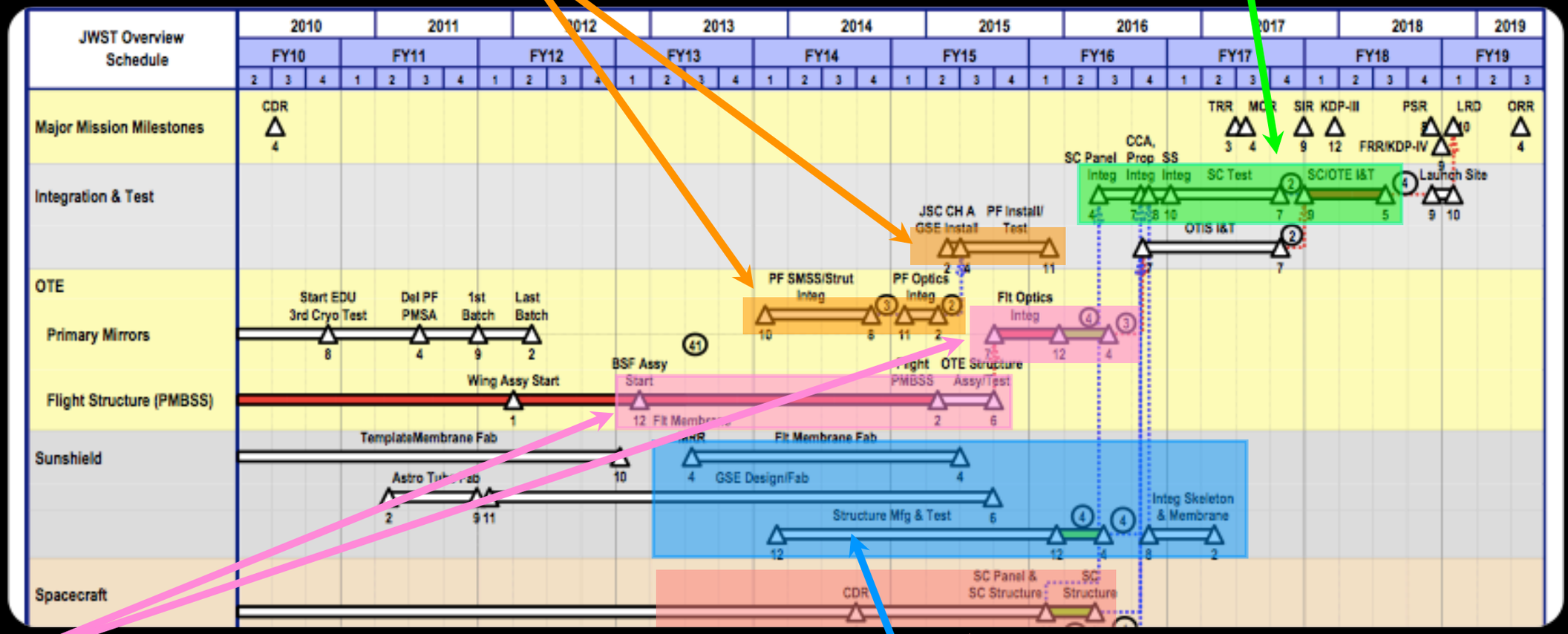
Secondary Mirror

Preparing for primary mirror integration

Observatory Schedule: What's Left?

Pathfinder backplane/SMSS - integration & test

Telescope/Sunshield/Spacecraft - integration & test

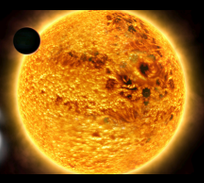


Primary Mirror Support Structure:
- Assembly completion and cryo-test
- Mirror population

Spacecraft: Fabrication & subsystem integration

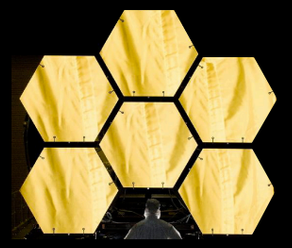
Sunshield Flight Membrane fabrication:
- Sunshield structure integration and test

JWST Capabilities: Transiting Systems



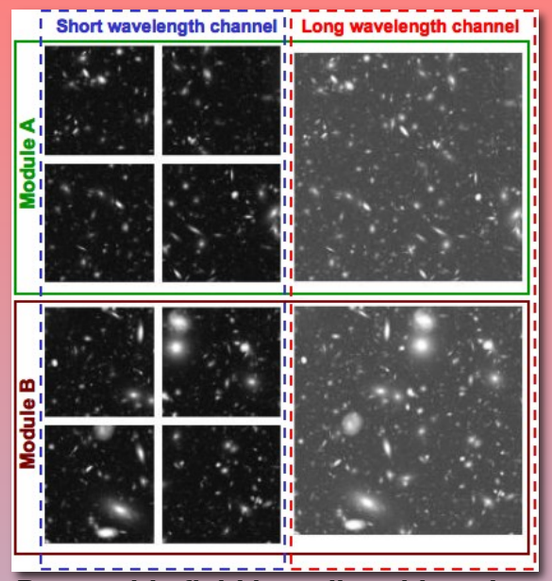
- **JWST is ideal for the characterization of transiting exoplanets**
  - ➡ Large, 6.5 meter aperture: SNR ≥ 10x current capabilities
  - ➡ Wavelength coverage: 0.6 μm – 29 μm
  - ➡ Excellent spectroscopic coverage
    - ➡ R = 100 to R = 2700 (NIR) & R = 100 to 3000 (MIR)
  - ➡ Optically stable platform: L2 orbit
  - ➡ Coverage: L2 Orbit
  - ➡ Well characterized detector systems

Transits: Observing Constraints



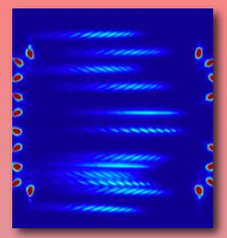
- **Instrument capabilities**
- **Observing Constraints**
  - ➡ Maximum exposure time: Coverage of transits
  - ➡ Sky visibility and duration: Accessibility of targets
  - ➡ Data volume limits: Duration of observations
- **Observing Error Sources**
  - ➡ Pointing error budgets: Motion of image on detector pixels
  - ➡ Pointing Telemetry: Data collection to track image motion
  - ➡ Detector performance: Detector limitations on performance
  - ➡ Image quality and Stability

JWST Science Instruments



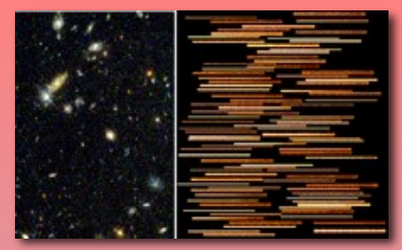
Deep, wide field broadband-imaging

Wavefront Sensing & Control (WFSC)

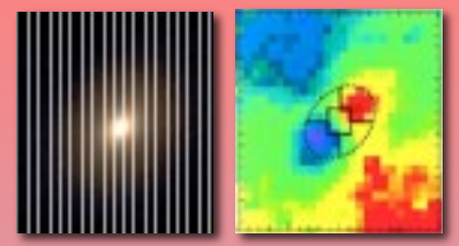


Coronagraphic Imaging

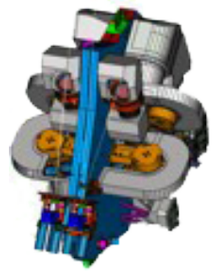
Multi-Object, IR spectroscopy



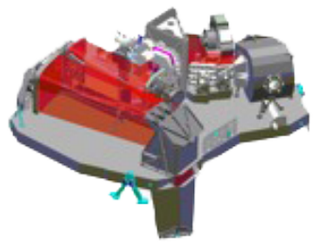
IFU spectroscopy



NIRCam

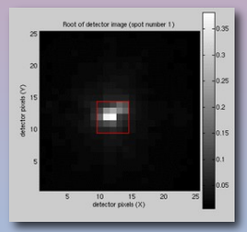


NIRSpec

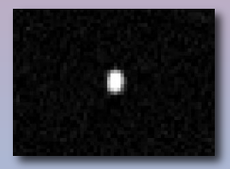


Long Slit spectroscopy

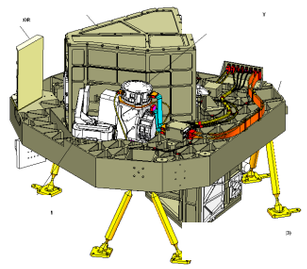
Fine Guidance Sensor



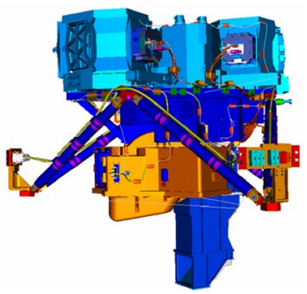
Moving Target Support



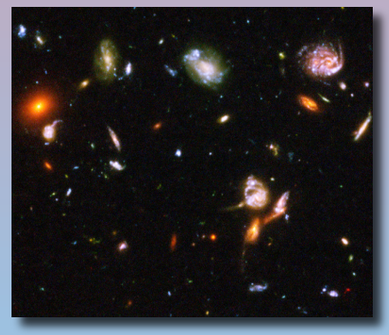
FGS/NIRISS



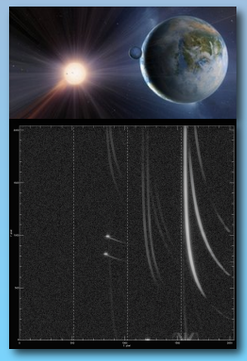
MIRI



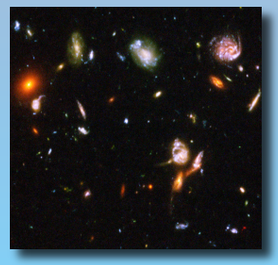
Mid-IR, wide-field Imaging



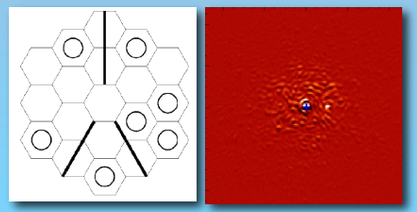
Slitless Spectroscopy



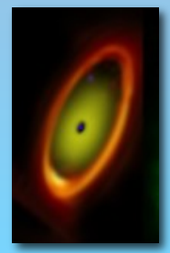
Near-IR imaging



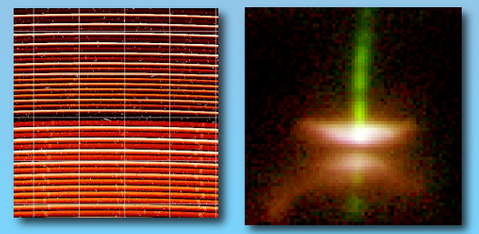
High Contrast Closure Phase Imaging



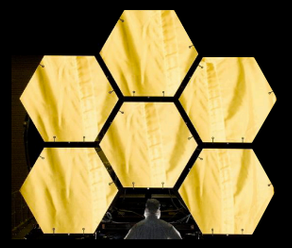
Mid-IR Coronagraphic Imaging



IFU spectroscopy

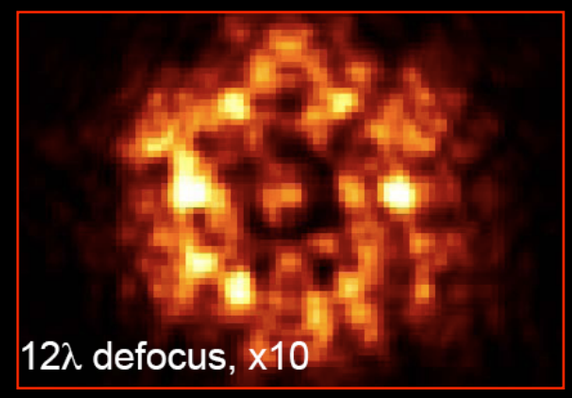


Near-Infrared Camera (NIRCam)



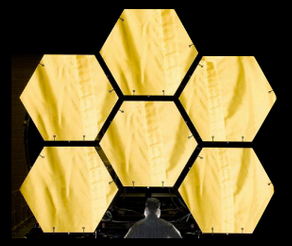
- **NIRCam capabilities**
  - ➡ Operating wavelength: 0.6 – 5.0 μm
  - ➡ Spectral resolutions: 4, 10, 100
  - ➡ Dichroic channel separation: monitor transit in 2nd channel

- Transit Photometry with 4λ, 8λ, 12λ defocused imaging
  - Smooths PSF - pixel sampling & avoid saturation bright targets
  - 4λ, 8λ, 12λ primarily for F212N & F187N filters

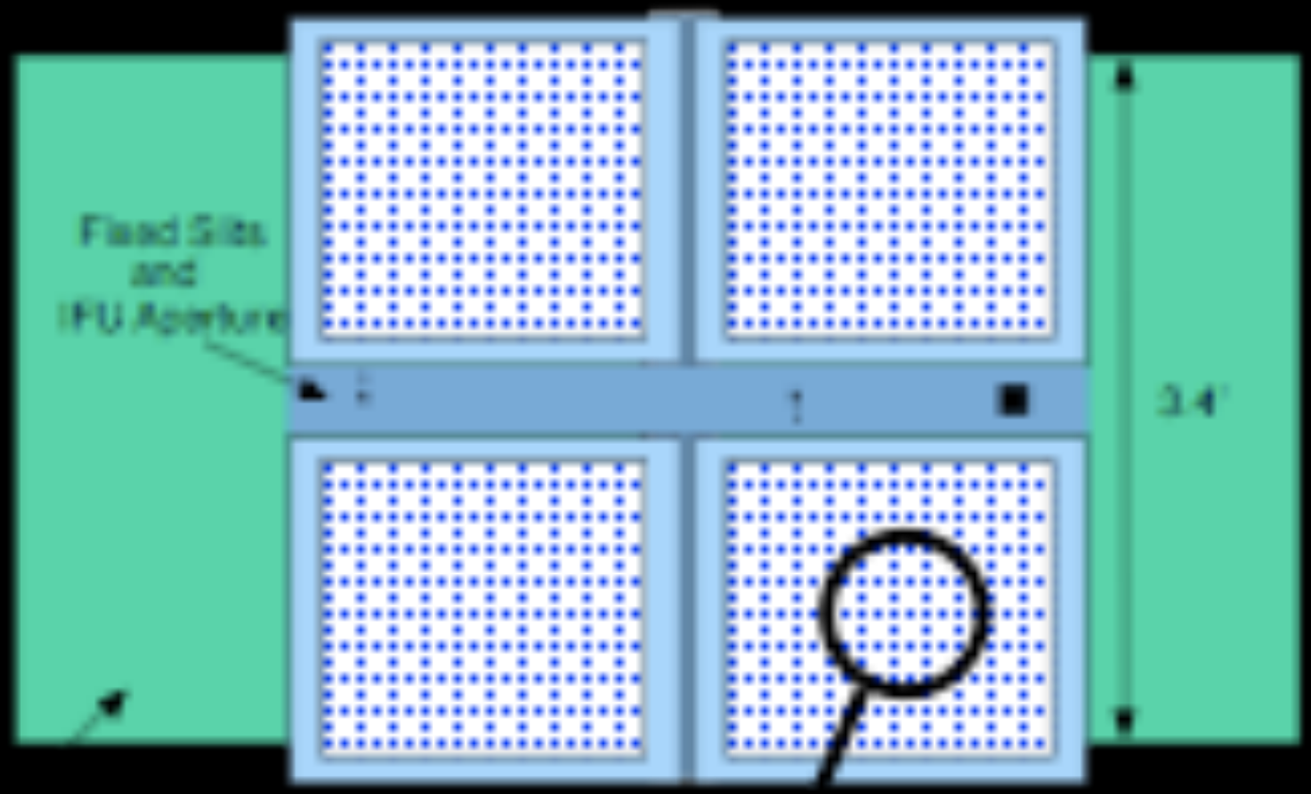


- Transit Spectroscopy
  - Slitless spectroscopy R~1700 w/broadband filters

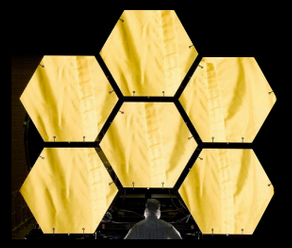
Near-Infrared Spectrograph (NIRSpec)



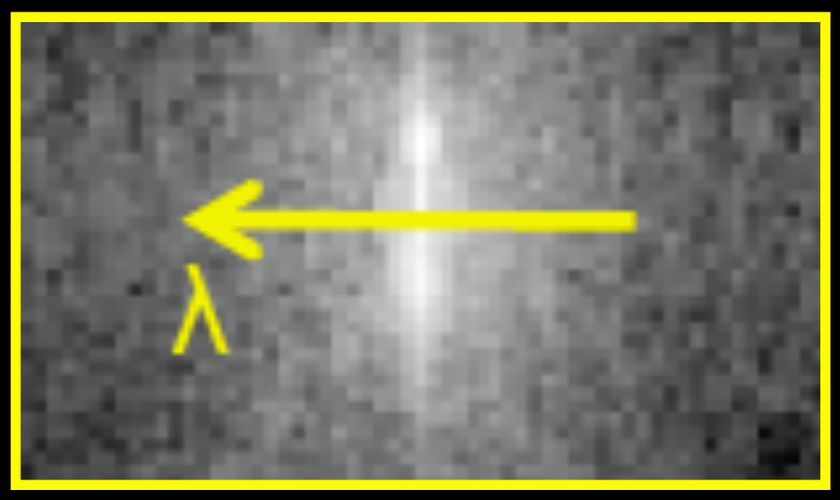
- Developed by European Space Agency and GSFC (MSA)
  - Operating wavelength: 0.6 – 5.0 μm
  - Spectral resolution: R = 100 (1 setting),
    R= 1000 & 3000 (multiple settings)
  - 1.6” x 1.6” fixed slit for transit spectroscopy

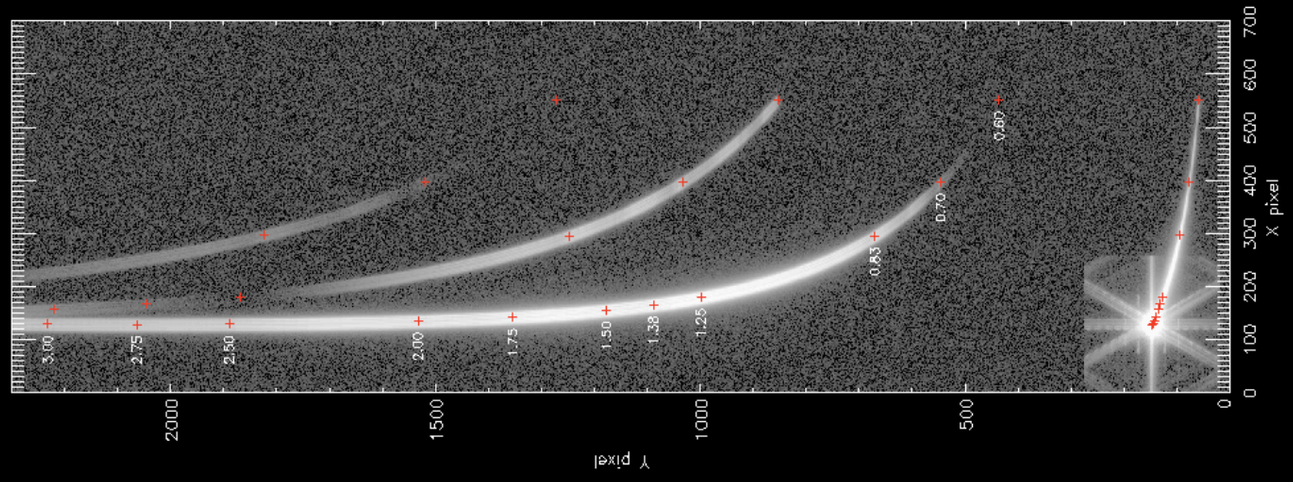


FGS/NIRISS

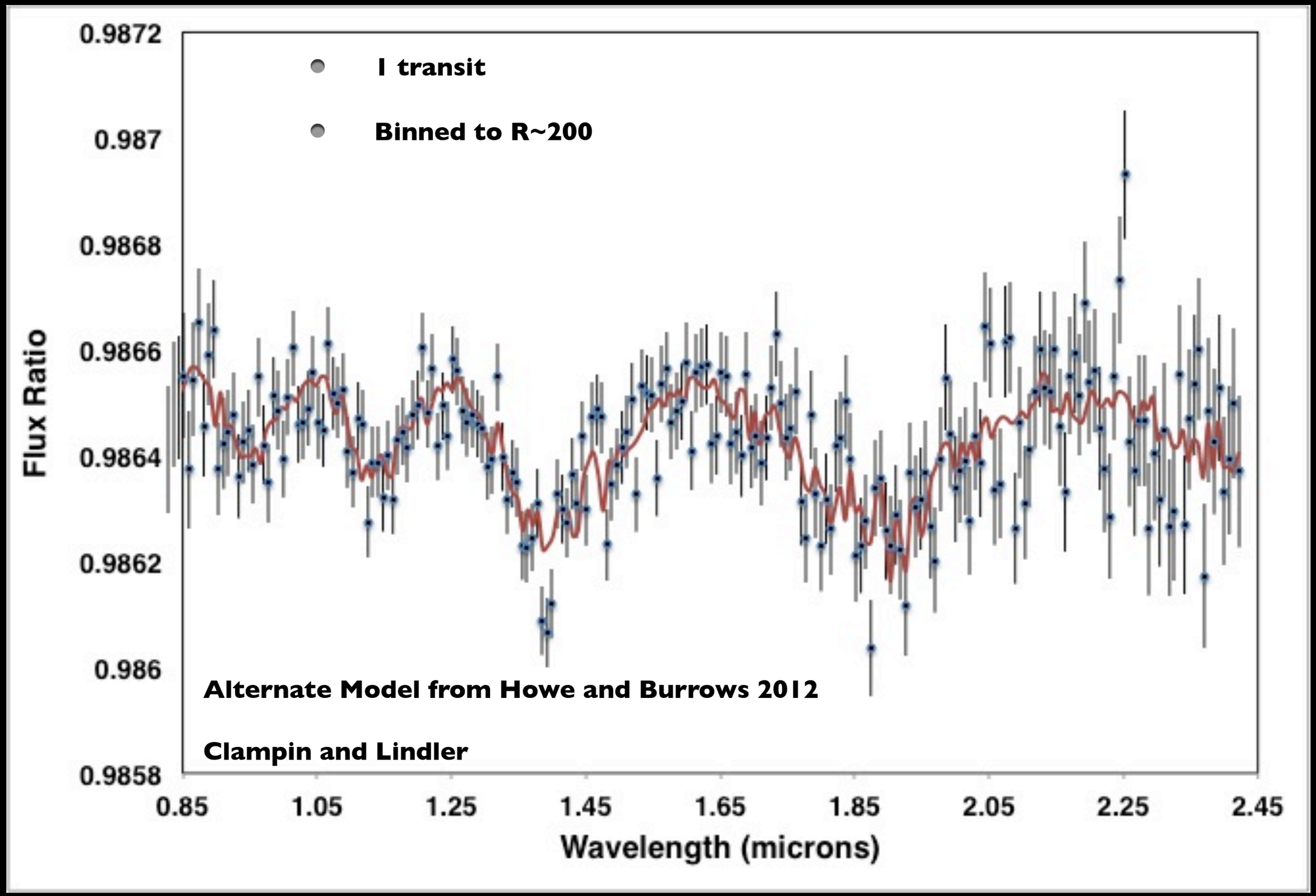


- Fine Guidance Sensor/Near-Infrared Imager & Slitless Spectrograph
- Developed by the Canadian Space Agency with ComDev
  - Operating wavelength: 0.8 – 4.8 μm
  - Transit Capabilities
    - Wide field grism: R150, 1– 2.5 μm
    - Exoplanet grism : R700. 0.6 - 3 μm w/Defocused Image in 1D
      - Excellent approach to minimizing systematic errors



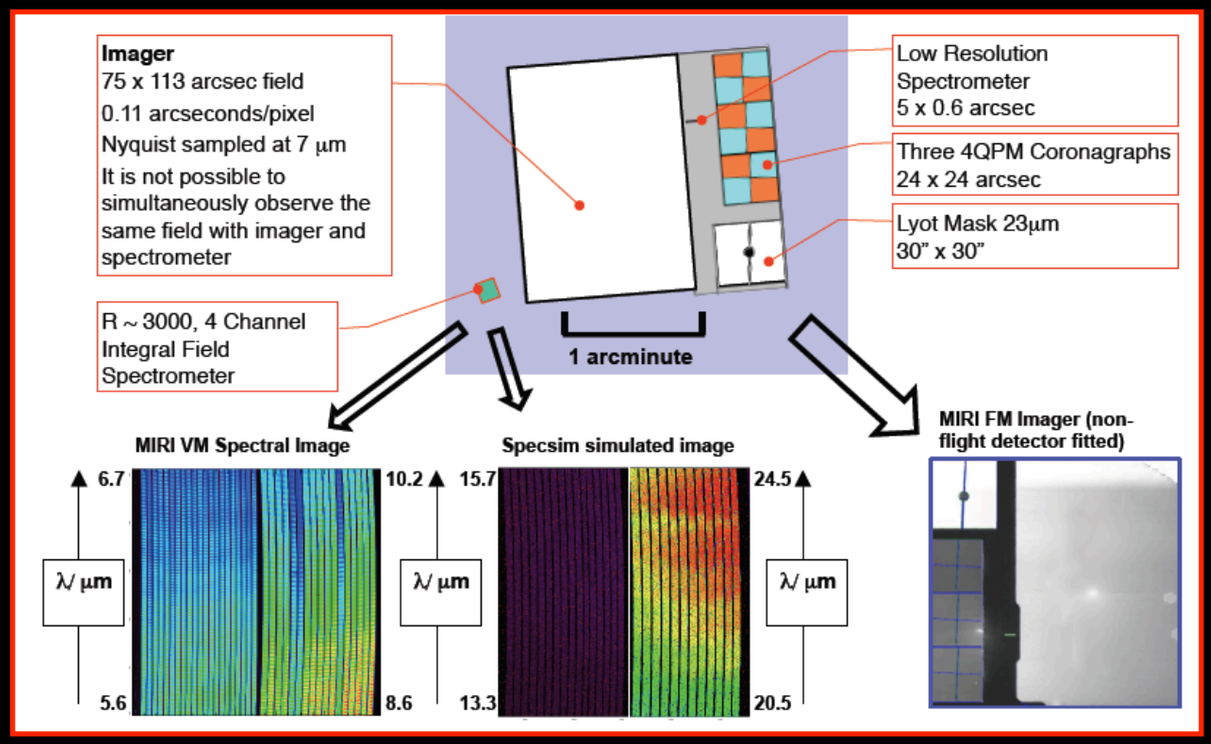


NIRISS Simulations: GJ1214b

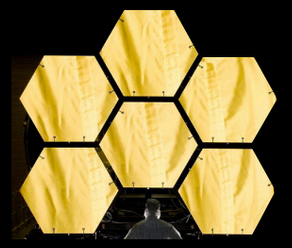


MIRI

- Developed by the MIRI European Consortium and JPL
  - Operating wavelength: 5 – 29 μm
  - Spectral resolution: 5, 100, 2000
  - Field of view: 1.9 x 1.4 arc minutes broad-band imagery
  - R=100 spectroscopy: slitless
  - R=2000 spectroscopy
  - 3.5 x 3.5 and 7 x 7 arc sec integral field units



Transits: Observing Constraints



- How long can we expose on a transiting system ?

- Maximum observing time imposed by spacecraft burns

  - ➡ Orbit station keeping:

    - ➡ JWST needs to conduct an orbit maneuver burn ~21 days to maintain its orbit around L2

  - ➡ **Momentum management burns**

    - ➡ Conducted as needed but no more than 8 times during 21 day stationkeeping interval, and not closer than 50 hours

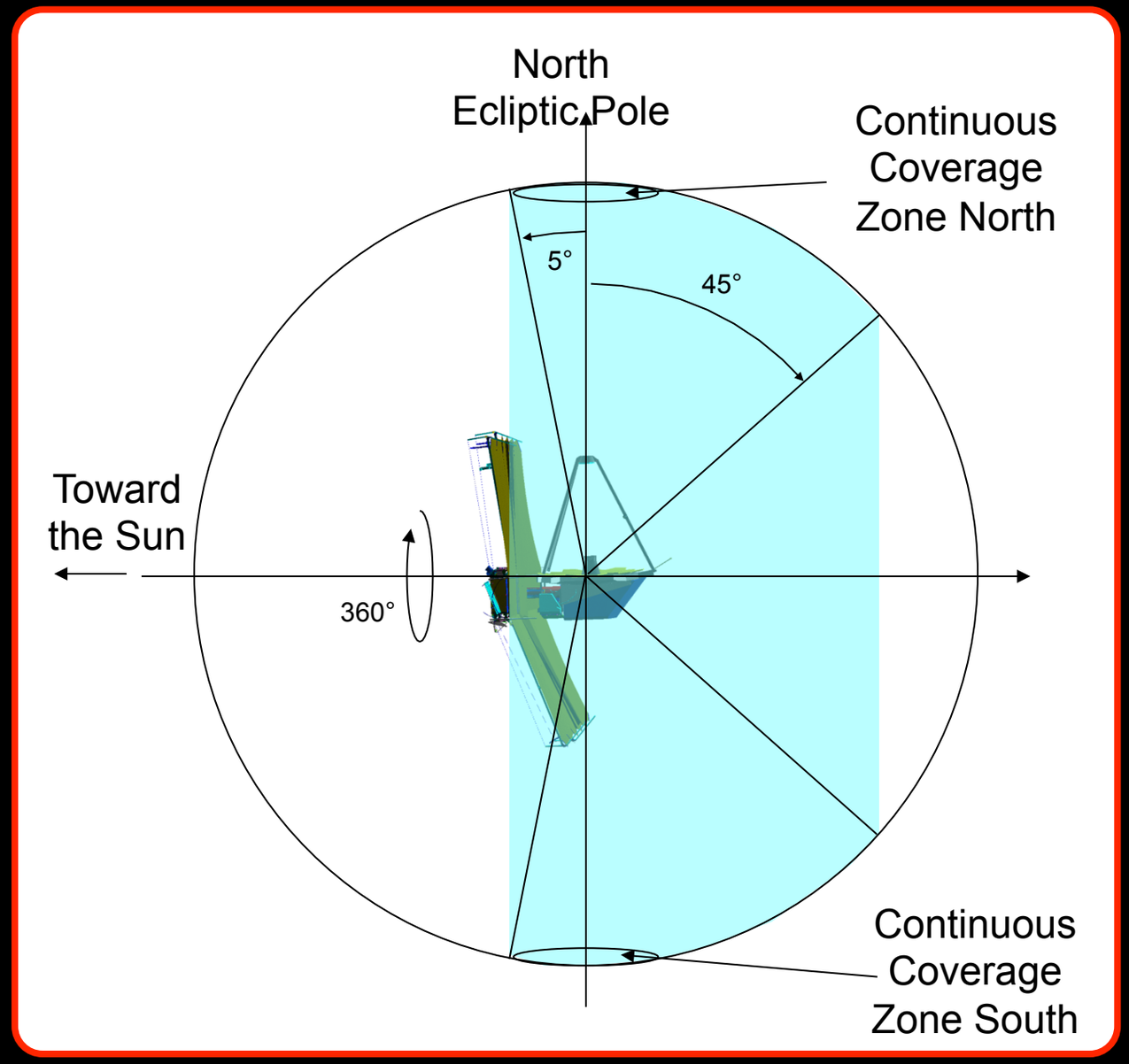
- **Maximum <u>uninterrupted</u> exposure time is ~50 hour**

Transits: Observing Constraints

- How much of the sky can we see at any given time ?

- Field of Regard is an annulus with rotational symmetry about the L2-Sun axis, 50° wide

- JWST has full sky coverage over a sidereal year



- Sun angle constraints yield coverage over 35% of sky at a given time

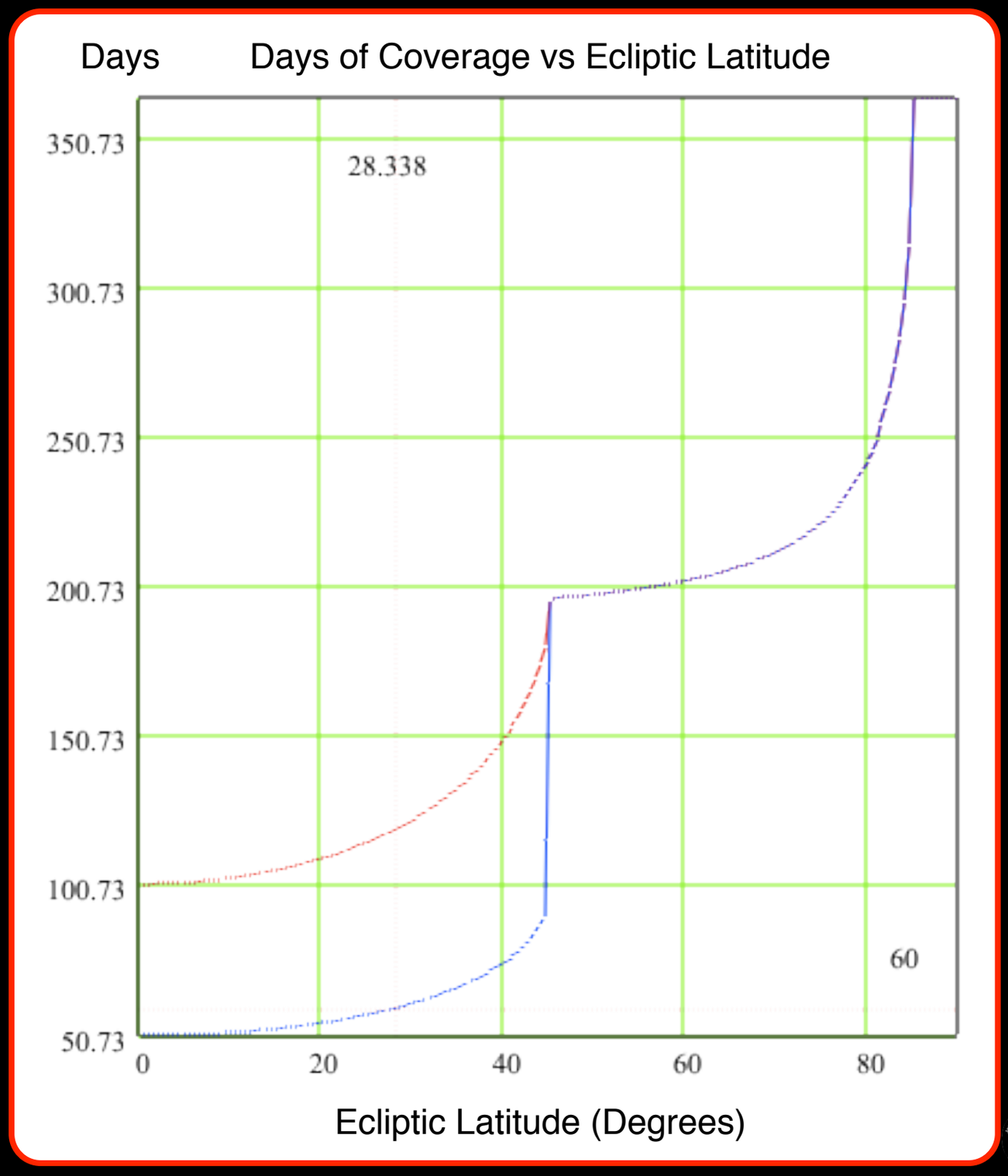
Transits: Observing Constraints

- Are there continous viewing zones for JWST ?

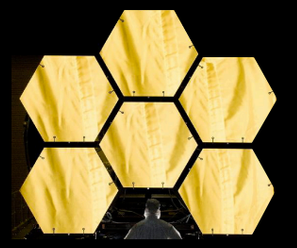
- There are continuous viewing zones 5° about the North and South Ecliptic Poles

- Chart shows that annual target coverage improves with proximity to the ecliptic poles

- Transit programs requiring multiple visits will want bright targets at higher latitudes



Transits: Observing Constraints



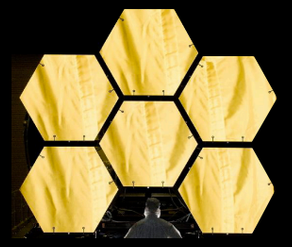
- **Is there sufficient storage space for transit observations ?**
- **Observatory Recorder: 471 Gbits Capacity**
  - ➡ 458 Gbits Science Data Partition
  - ➡ 12.6 Gbits Engineering Data Partition
  - ➡ 0.2 Gbits Critical Telemetry Partition
- **Ground contacts: Two 4 hour contacts every 24 hours**
  - ➡ 229 Gbits download every contact
- ☑ **Data volume will not an issue for single target transit imaging and spectroscopy programs**
  - ☐ High-cadence, full-frame NIRCam imaging programs could violate data volume e.g. monitoring programs such as SWEEPS

Transits: Systematic Errors

- **Will Pointing Jitter be a major systematic error?**
  - ➡ NIRSPec has added a large 1.6” x 1.6” slit for transit science
  - ➡ NIRISS/NIRCam/MIRI offer slitless spectroscopic modes
  - ➡ JWST pointing budget recently revised to better define control of jitter during short exposure observations for a range of science
    - ➡ Detailed allocations for jitter & drift permit science modeling to assess impact of jitter/drift

- **If I want to decorrelate jitter what data is available?**
  - ➡ FGS provides telemetry: guide star centroids every 60 sec
  - ➡ Option for guide star thumbnail images

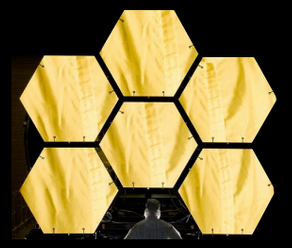
Transits: Systematic Errors



- **If I want to decorrelate jitter what data is available?**
  - ➡ HgCdTe near-IR detector pixel response function (PRF) has been measured by FGS team and is being re-measured for new JWST HgCdTe detectors
  - ➡ Mid-IR MIRI detector PRF cannot be measured on ground

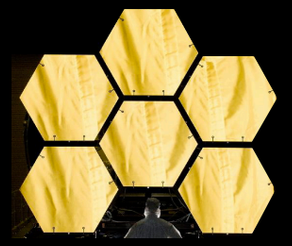
- **Is it possible to calibrate the structure of detector pixels on-orbit to facilitate jitter decorrelation for MIRI ?**
  - ➡ Added option for Fine Steering Mirror (FSM) to step a star around a detector pixel once JWST is on-orbit
    - ➡ **FSM offsets permit precision mapping of detector PRFs, with few mas step size for all science instruments**

Transits: Systematic Errors



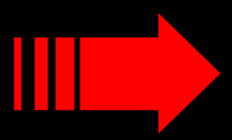
- **Image Quality**
  - ➡ JWST's image quality slowly degrades due to thermal/ dynamically induced mis-alignments of the optical system
  - ➡ Wavefront sensing and control (WFSC) is employed to fine tune the optical train's wavefront error every two weeks
    - ➡ A wavefront sensing measurement made every ~2 days
      - ➡ PSF is measured across WFSC cycle
    - ➡ Wavefront control nominally every 14 days:
      - ➡ Mirrors adjusted to fine tune image quality

Transits: Systematic Errors



- Wavefront error drift is specified against a worst case cold soak to hot soak followed by 14 days
  - Translates to ≤ 3% encircled energy change over 14 days

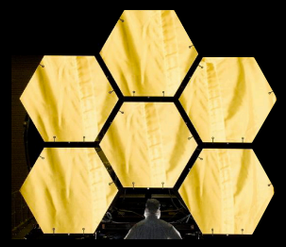
Cold Case Operational
0° Roll, –45° Pitch



Hot Case Operational
0° Roll, +5° Pitch

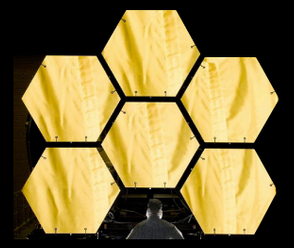
- **JWST's image quality will be very stable, as real science operations are more thermally benign than worst case used for requirement verification**
- **Thermal performance will be characterized during commissioning of observatory**
- **PSF will be stable for duration of a transit observation**

Transits: Systematic Errors

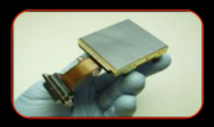


- **Science Instruments offer two types of detectors**
  - MIRI: SiAs arrays for mid-IR
  - NIRCam/NIRISS/NIRSpec
    - HgCdTe arrays: 1 - 5 μm, 1 - 2.5 μm & 2.5 - 5 μm
    - ASIC direct to digital readout
- Detector calibration issues:
  - Residual images
    - excellent input from WFC3 programs on HST
    - expect that decorrelation may be required
  - NIRSpec team investigating noise reduction processing

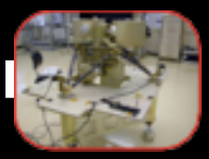
Pre-Launch Calibration



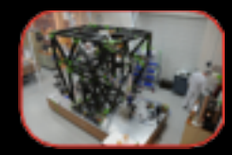
- **JWST will have multiple levels of testing prior to launch**
  - ➡ Sub-system: e.g. detector characterization



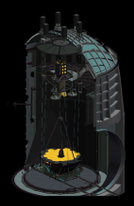
  - ➡ **Instrument level cryogenic characterizatio**



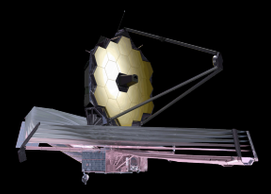
  - ➡ **ISIM (4 instrument) cryogenic testing**



  - ➡ **Observatory level testing in Chamber-A (JSC)**

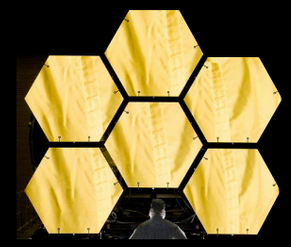


  - ➡ **Observatory commissioning at L2**



- **JWST integration and test program offers multiple opportunities for calibration and testing of science instruments**
  - ➡ **Science instrument teams are looking at needs of transit science programs**

Exoplanet Observing



- JWST science program will operate in a similar way to HST
  - ➡ Science programs will be selected by peer review

- Exoplanet science will be a major element of JWST science
  - ➡ Program and Science Teams working to make sure that JWST is ready to undertake exoplanet transit programs
  - ➡ New Whitepaper shortly, discussing these issues in detail
  - ➡ New capabilities added for transit science
  - ➡ Extensive ground testing program will provide excellent working knowledge of detector characteristics